Congestion Management in Deregulated Electric Power System Using Distributed Power Flow Controller (DPFC)

A Synopsis

Submitted by

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1. Introduction

With the increase in demand for electric power, the congestion in the network become a major issue and if congestion is not managed, it may lead to violation of thermal limits. With the violation of limits, transmission lines may not be utilized completelyand transfer capability of transmission line is reduced if congestion is present (Bhattacharya, et al., 2018). There is a list of methods to manage the congestion in electrical network, which includes technical and non-technical means. Technical means includes outages of congested line, transformer tap changer and FACTS devices. Non-technical means includes market based and non-market based methods.

FACTS devices are implemented in the transmission line system in order to improve transmission system voltage stability, power flow and transmission system security. FACTS controllers are successfully used in the system as they maximize the system controllability and power transfer in the transmission line network. Following is the list of controllers available for the implementation:

a) Series connected controller
b) Shunt connected controller
c) Combined Series-Series connected controller
d) Combined Series-Shunt controller

These controllers have been installed in the transmission network in recent years, and they are critical for supplying sufficient power to end customers. The primary goal of FACTS device placement could be one of the following:

a) In a specific line, real power loss should be decreased.
b) Increasing efficiency by lowering overall system real power loss
c) To reduce the power system's reactive power loss.
d) To alleviate system congestion to the greatest extent possible.

The first three objectives can be met using strategies based on the sensitivity approach. The location of FACTS devices is planned to give maximum power system congestion reduction. The gadgets could be installed on the busiest lines or at areas discovered by trial and error. A good power performance is measured as the system's ability to supply clean and stable power with less than permissible frequency and magnitude fluctuations from nominal values and no harmonics. Power quality is also described as the ability of a power system to offer clean and stable power. Poor power quality causes control devices and relays to malfunction or operate incorrectly, as well as additional losses in transformers and equipment.Assessing power issues in the power system and making recommendations for the best power quality management is also critical. Voltage sag and harmonics cause power flow disturbances, they have great impact on sensitive equipment. To mitigate these disturbances, voltage sag compensation and harmonic reduction in electrical power system network is required.

2. Literature Survey

In restructured electric power system, congestion throughout the transmission lines is one of the common issue due to the increasing demand for electric power to meet the consumer needs. To mitigate congestion in the transmission system need for compensating devices were in demand which mitigates the congestion issues very effectively without making changes in the transmission line parameters. FACTS technology came into existence in form of compensators which were installed on transmission lines and results in increased real power and that too maintain the parameters within limits. Optimal location of the FACTS devices became the major challenge which was further studied and performed with various methods mentioned in literature and found to be effective. As per the researchers they have adopted various optimization techniques to pin point the appropriate location for the controller, such as Genetic Algorithm, Neural Network, Particle Swam Optimization techniques, etc.One of the optimization technique introduced in 2015 named as Artificial Algae Algorithm. The research papers under Artificial Algae Algorithm describes the recently developed bio-inspired optimization algorithm. This

optimization technique has been introduced by inspiration from living behavior of micro algae. Author verified the algorithm on various benchmark function and a real-world design optimization problem. Multi-light source (AAA_{ML}) version was established. Performance of AAA with proposed operator (AAA_{ML}), were experimented and result showed the MLS movement increased the success of AAA (Uymaz& Tezel, 2015). The topologies of FACTS devices as per construction of the converters, major challenge faced by the researchers were the cost of FACTS devices. Also, environment friendly devices should be encouraged so as to increase the life span of the system and also to somewhat reduce the cost as FACTS devices are costly devices, which increases the overall cost of the installed system.

3. Problem Formulation

Considering the research work in the field of congestion management in transmission lines which is very necessary to be controlled. Few of the transmission lines may not be utilized completely due to various issues which causes limit violations such as thermal limit and also cause power quality issues. These problems are to be solved for the proper power flow in order to meet the consumer demand with no or minimum power losses and keeping the electrical parameters under the designated limits. In this thesis, it is proposed the modeling a Distributed Power Flow Controller with PEM Fuel Cell and Z source inverter for power quality improvement under the title,

"Congestion Management in Deregulated Electric Power System Using Distributed Power Flow Controller (DPFC)". The performance of the system is checked with and without proposed model.

4. Objectives of the Research Work

Considering the issues in electrical power transmission throughout the network and in order to meet the consumer demand for power with minimum losses and maximum output following objectives are considered in this research work:

To design a Novel Distributed Power Flow Controller (DPFC) with Fuel Cell and Z source inverter for power quality improvement.

a) To enhance power flow in the electrical system by optimal placement of DPFC using appropriate optimization algorithm.
b) To compare the proposed model with other FACTS devices available in the literature.

5. Organization of proposed research work and Methodology

MATLAB/SIMULINK is used to design the DPFC. Artificial Algae Algorithm is the optimization technique used for the optimal placement of the DPFC in the transmission line network.

Figure 1 describes the organization of proposed research work and the methodology used to meet the following objectives:

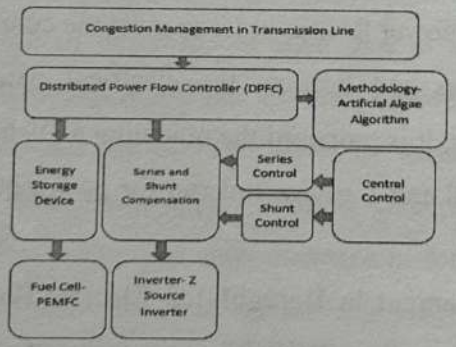


Figure 1 Organization of Research Work with Methodology

The DPFC can be thought of as a UPFC that uses the D-FACTS concept and the concept of power exchange using harmonics. As a result, the DPFC combines the benefits of both the UPFC and the D-FACTS. The complete method is based on power theory of non-sinusoidal components (Faiz, et al., 2010).The new Distributed Power Flow Controller (DFPC) idea is introduced in this thesis with a fuel cell and Z-

source inverter proton exchange membrane (PEM).The entire design has been made and simulated in MATLAB/ SIMULINK environment.

In the proposed DPFC model with PEM fuel cell, a Z Source Inverter (ZSI) is used. The ZSI's only feature is the ability to boost/buck the output voltage via operation mode, which is disallowed in typical voltage source inverters (Ahmed, et al., 2019),with this feature, ZSI provides a cheaper, simpler buck boost reversal via single power conversion, good EMI immunity, and low harmonic distortion (Rabi &Arumungam, 2010).

Various algorithms have also been developed with the help of which it is feasible now to efficiently place FACTS devices in the power system, something that has drastically reduced the cost of operation and also has improved the quality of power transfer (Pham, et al., 2006), this research proposes a method to improve power transfer capability of the system with the proposed DPFC with a PEM fuel cell (Chakravorty, et al., 2018). The optimal location of the proposed DPFC has been decided with the help of Artificial Algae Algorithm (Chakravorty & Saraswat, 2019). The complete proposed system has been simulated in MATLAB/SIMULINK and the result has been compared with the system without DPFC in it.

The algorithmic steps of the application of AAA in optimal placement of DPFC with PEM are:

1) Randomly select DPFC parameters V_{se} and V_{sh}.
2) Perform load flow analysis of the system.
3) From the obtained result of step 2, calculate the value of the objective function.
4) Select the minimum value of the objective function as the best algae solution.
5) Update the algae colony using helical movement.
6) Perform the operation of reproduction and adaptation.
7) Repeat steps 2-4.
8) Compare the two outputs. If the stopping condition.

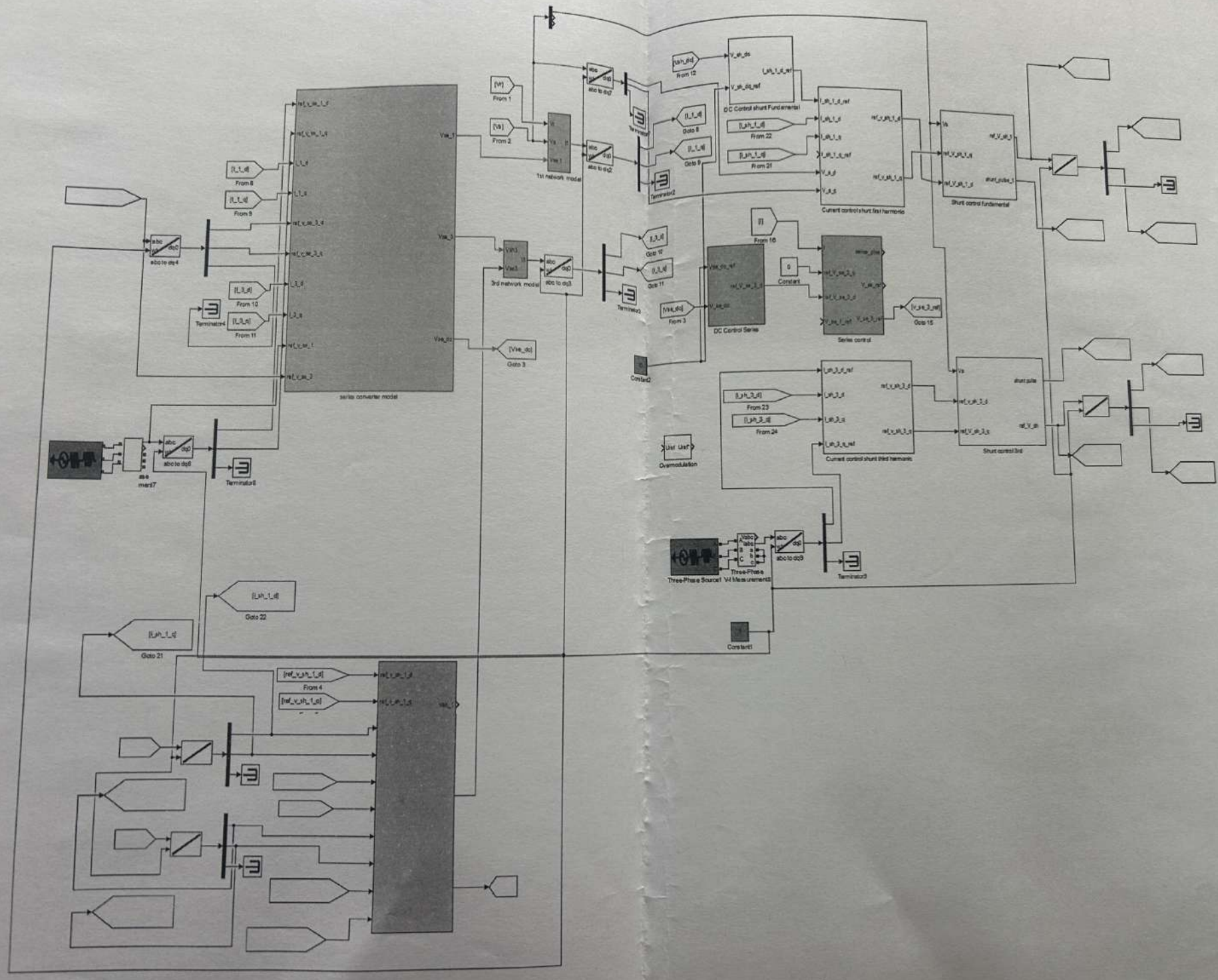
The proposed algorithm has been tested with standard IEEE 14 bus system. Numerical data and parameters are given in Appendix III. The proposed IEEE-14 bus system has 19 lines, 11 load buses, 1 slack bus and 2 generator buses. The load flow analysis is performed using the Newton Raphson method in the IEEE 14 bus system and the ranking is obtained by contingency analysis. The transformer ratio varies from its nominal value during the calculation process. First, the process assumes one DPFC is required to be placed in the system then the process is repeated for two DPFCs.

6. Results and Discussions

The Distributed Power Flow Controller (DPFC) with fuzzy PWM technique, which was discussed and designed in MATLAB has been tested in IEEE-14 bus system. The model is tested using the data shown in Table 1.

Table 1: Test Data

Parameter	Values
Sending end voltage	230 V
Receiving end voltage	230 V
Frequency	50 Hz
Vsh DC	20 V
Vse DC	20 V
Ish,3 ref	03:00 AM
Series Capacitor	1 μF
Shunt Capacitor	1 μF
Length of transmission line	100 km
Line resistance	0.45 Ω/Km
Line inductance	4.2 mH/Km
X/R ratio	3


From 1
From 2
abc to dq7
abc to dq2
1st network model
Terminator7
Terminator2
Goto 8
Goto 9
From 12
DC Control shunt Fundamental
From 22
From 21
Current control shunt first harmonic
Shunt control fundamental
From 8
From 9
abc to dq4
From 10
From 11
Terminator4
series converter model
Vse_1
Vse_3
Vse_dc
3rd network model
abc to dq3
Goto 10
Goto 11
Terminator1
Goto 3
From 16
Constant
DC Control Series
From 3
Series control
Goto 15
Constant2
From 23
From 24
Current control shunt third harmonic
Shunt control 3rd
Overmodulation
Three-Phase Source1
V-I Measurement3
abc to dq9
Terminator3
Constant1
Goto 22
Goto 21
From 4
abc to dq8
Terminator8

The voltage waveform with and without proposed DPFC with fuzzy PWM model is shown in figure 2. Similarly the current waveform with and without the proposed DPFC with fuzzy PWM model is shown in figure 3.

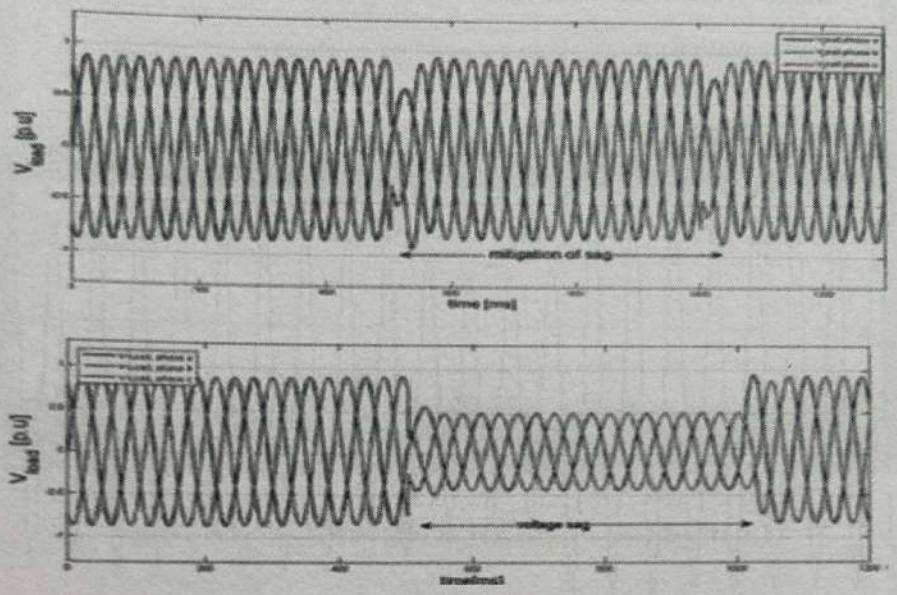


Figure 2 Voltage waveform of two parallel line test network with and without proposed DPFC

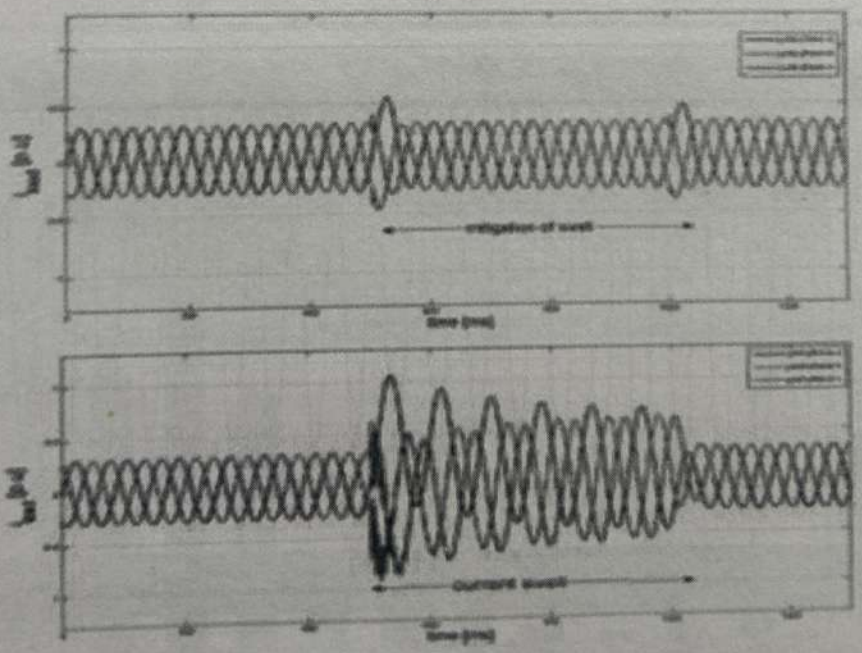


Figure 3 Current waveform of two parallel line test network with and without proposed DPFC

Similarly, the voltage waveform of the test results for the IEEE–14 bus system with and without the suggested DPFC is shown in Figure 4. Figure 5 depicts the DPFC's voltage waveform with and without DPFC in the system. Figure 6 describing the power waveform.

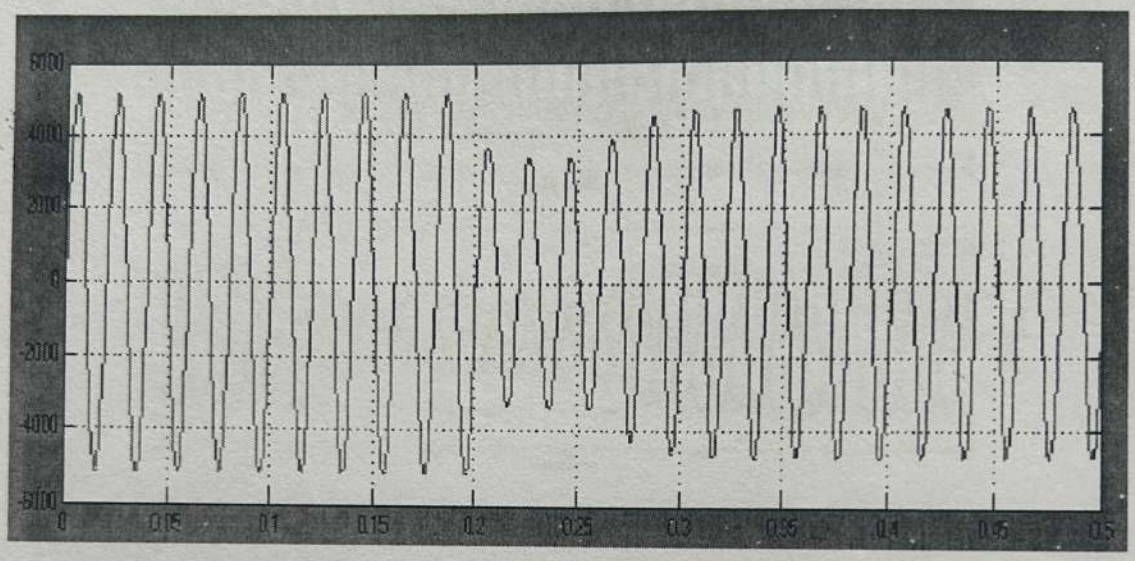


Figure 4 Voltage Waveform with DPFC (IEEE-14 bus system)

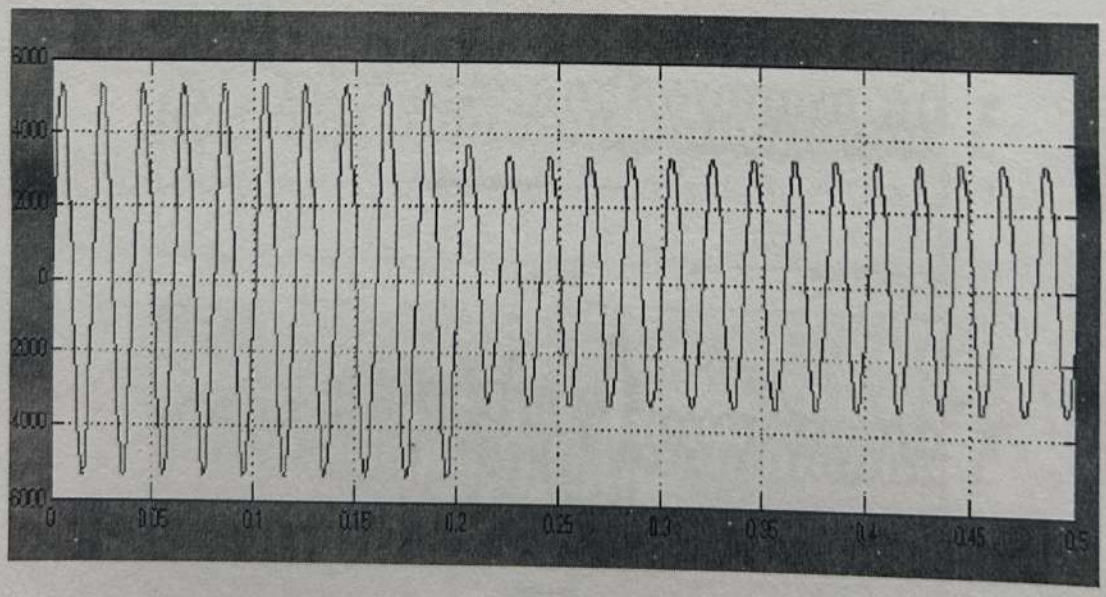


Figure 5 Voltage Waveform without DPFC (IEEE-14 bus system)

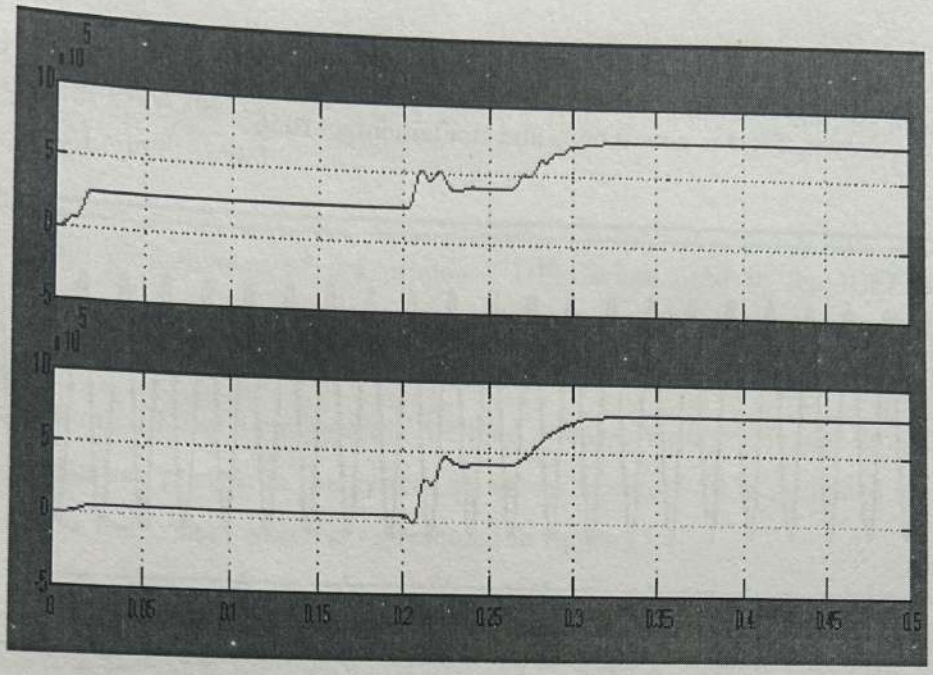


Figure 6 Power waveform (IEEE-14 Bus System)

The FFT analysis of Z source inverter is shown in figure 7. As shown, THD=287.23% and fundamental=36.35.

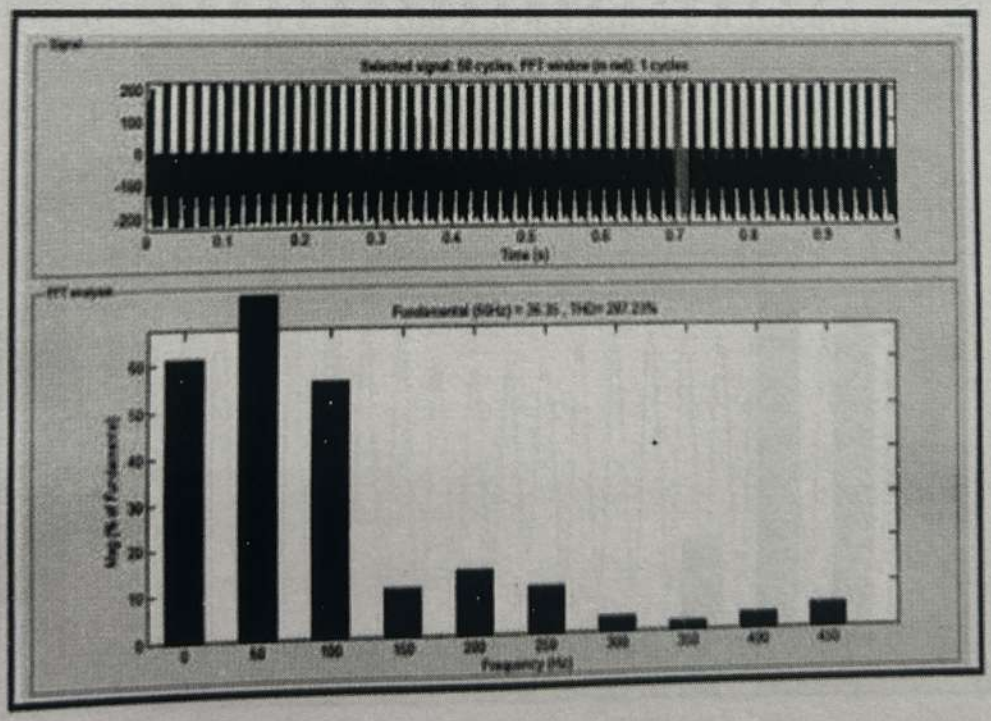


Figure 7 FFT analysis of Z source Inverter

To compensate this, an LC filter is employed. The filtered output is shown in Figure 8. As shown, THD is now 0.66% and fundamental=1056.

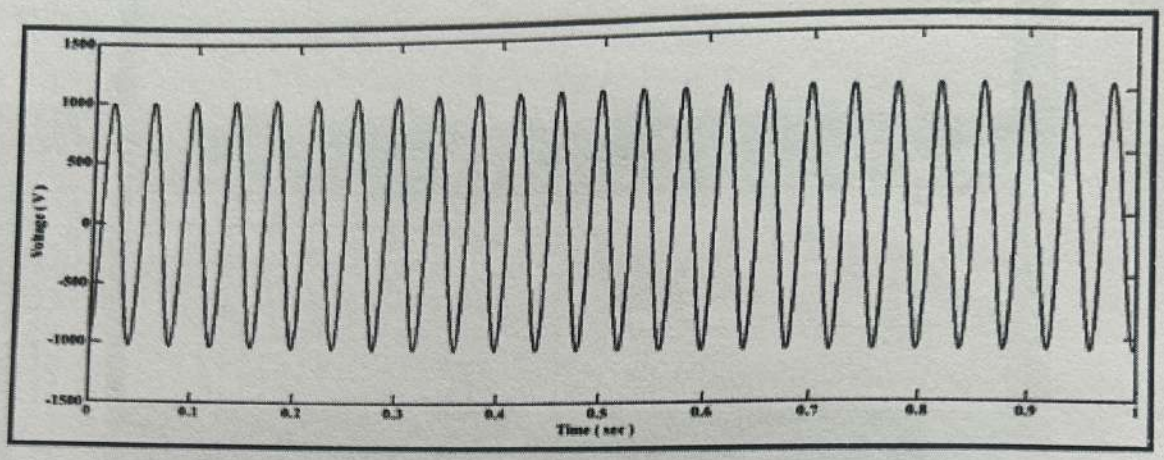


Figure 8 Filtered Output Voltage of Z Source Inverter

The FFT analysis of Z source inverter with filter is shown in Figure 9.

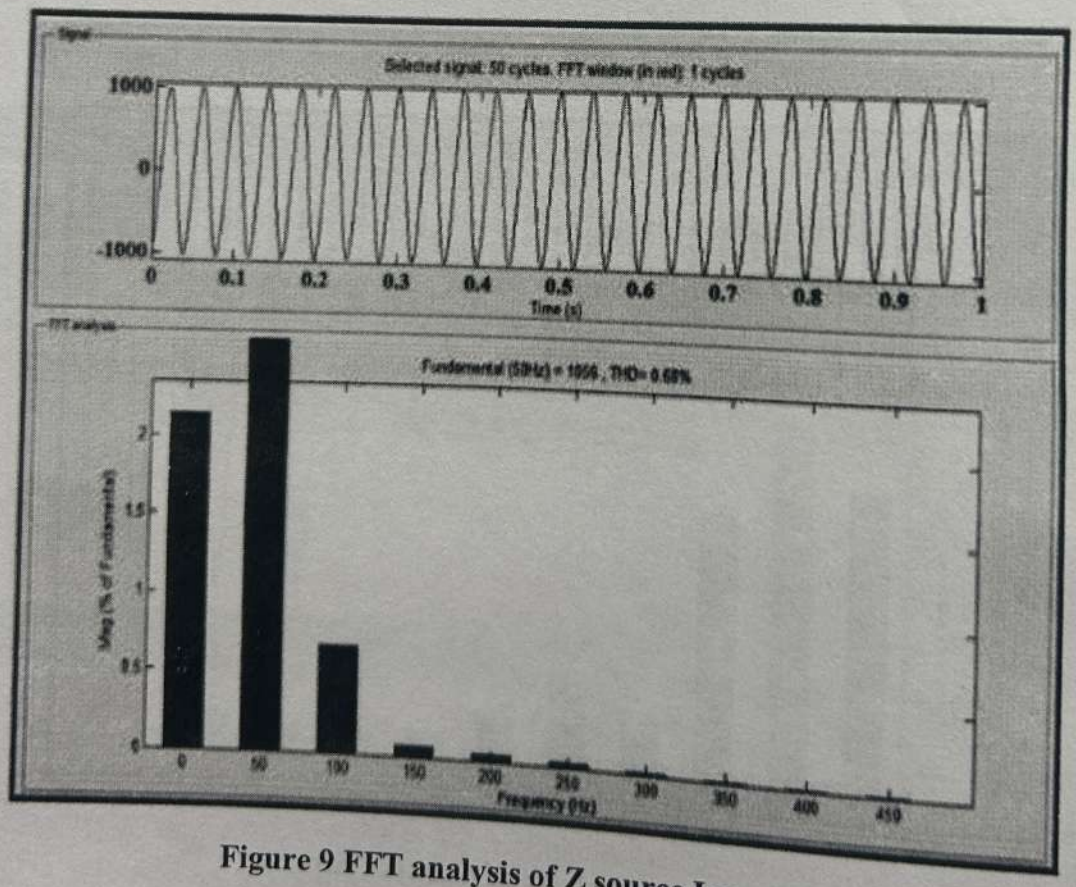


Figure 9 FFT analysis of Z source Inverter

From the above analysis it is clear that the performance of the Z source inverter with PEM fuel cell gave satisfactory results. This inverter will be used with the proposed DPFC model.

The performance of the proposed DPFCwhen used in the IEEE 30 bus system is shown in figures 10 to 13.

Figure 10 and 11 represents the load voltage, v on y-axis and time, t on x-axis. Voltage sag present in the system as shown in figure 10 is mitigated by DPFC placement in the system which is represented in figure 11.

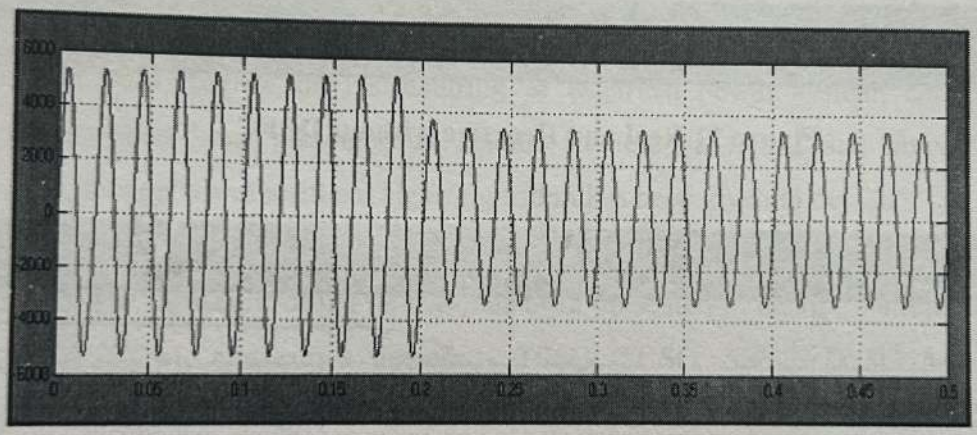


Figure 10 Load voltage without DPFC

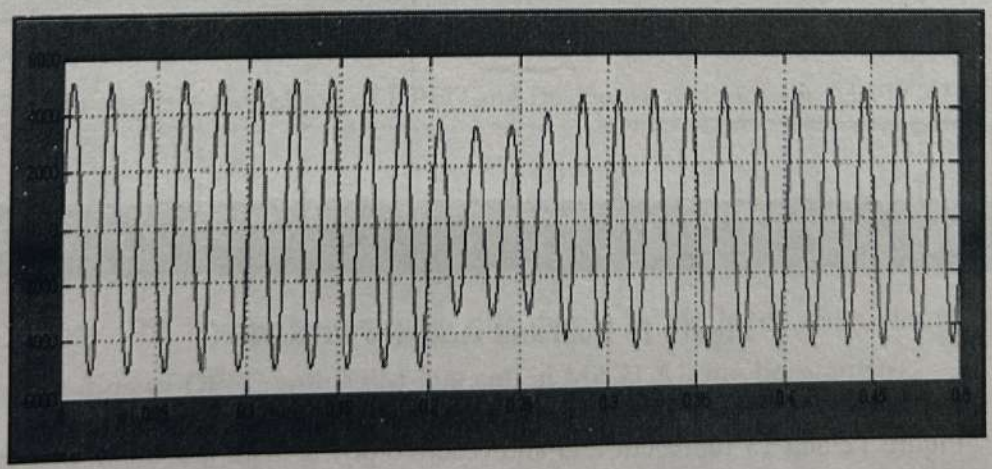


Figure 11 Load voltage with DPFC

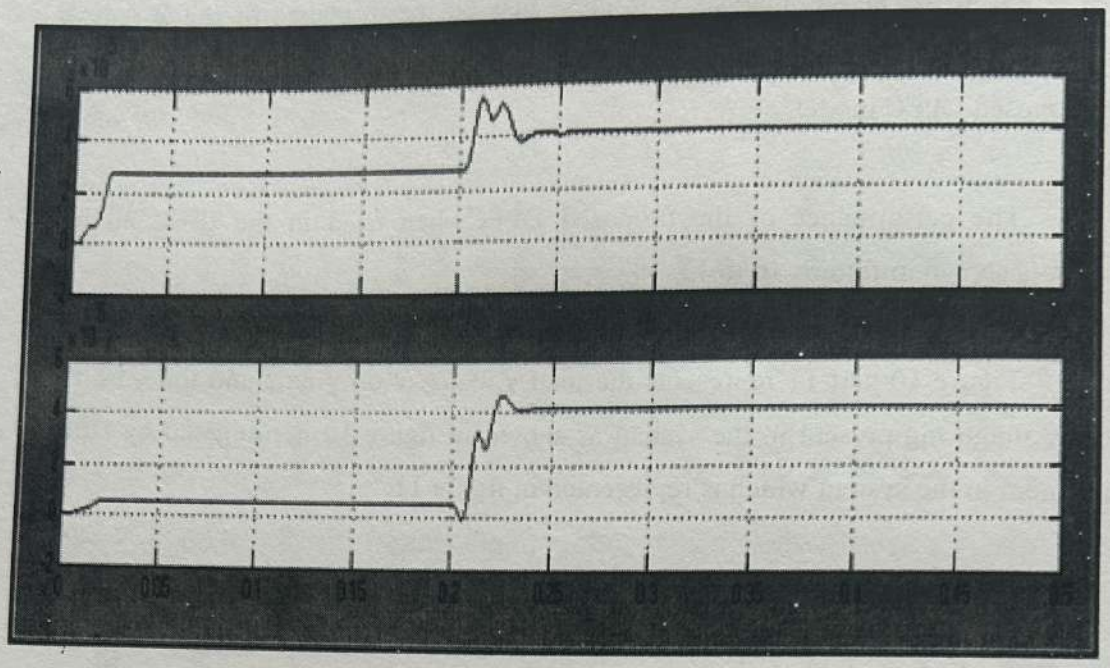


Figure 12 Real and Reactive without DPFC

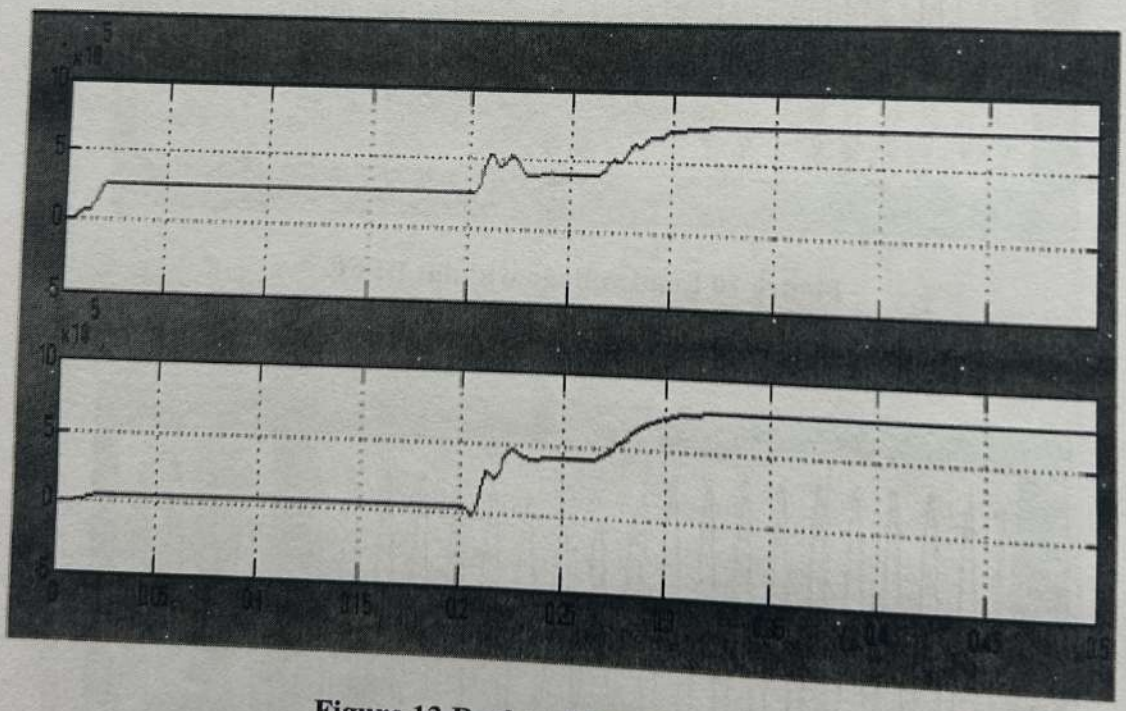


Figure 13 Real and Reactive with DPFC

Figure 12 and 13 represent real and reactive power with and without DPFC. Y-axis represents power, time is on x-axis. Figure 13 representing improved real and reactive power with implanting DPFC in the system.

7. Conclusion

This section presents the summary of the observations made during the entire research work and also suggests possible future scopes in the area of distribution system networks.

This thesis presents some introductory aspects of electric power system marketing, issues related to deregulated energy market, method to manage congestion in transmission line, power quality and harmonics, different types of FACTS controllers and applications, fuel cells.

Extensive literature survey pertaining to the research is being presented under Literature Review on restructuring of electrical power system, congestion management had been presented in details. Review on DPFC and power flow controller, fuel cells and artificial algae algorithm has been given in details.

Power flow controlling devices has been presented in detail. Shunt devices - SVC, STATCOM, and series devices - TSSC, TCSC, SSSC, DSSC has been discussed with the configurations. It also includes, combined series and parallel devices like PST, IPFC, UPFC, DPFC.

Distributed Power Flow Controller (DPFC) has been discussed in detail with its configuration. Components of DPFC, operation of DPFC, control strategies of DPFC and complete modelling of DPFC and its control technique in MATLAB.

PEM fuel cell, Z source inverter and implementation of the same in MATLAB. Comparison between majorly used fuel cells and comparison between CSI,VSI and ZSI is also presented in this thesis. In the latter stage, the complete implementation of DPFC with PEM fuel cell in MATLAB has been given.

The optimal location of DPFC in transmission line using artificial algae algorithm has been proposed. The performance of the proposed DPFC model, has

been tested in transmission line. Where the system performance without DPFC, with one DPFC and with two DPFC in the system has been compared. Also the real power loss and reactive power loss in the system at normal load, at 125 % of load and 150% of load were calculated.

The simulated results of the proposed new DPFC model with PEM fuel cell are given. The simulated results include the following:

i. Voltage waveform of two parallel test system with and without proposed DPFC
ii. Current waveform of two parallel test system with and without proposed DPFC
iii. Voltage waveform with and without DPFC (IEEE-14 bus system)
iv. Power waveform IEEE-14 bus system
v. Comparative analysis with other FACTS devices available in the literature.
vi. DC link voltage of ZSI
vii. FET analysis of ZSI
viii. Output voltage of inverter.
ix. DPFC steady state line current
x. DPFC steady state bus voltage and current in delta side of the transformer.
xi. Series converter voltage
xii. Line current
xiii. Active and reactive power injected by series converter at fundamental frequency.
xiv. Load voltage with and without DPFC
xv. Real and reactive power with and without DPFC

The complete analysis of the research work shows that the proposed DPFC with PEM fuel cell and Z source inverter when properly installed in the system improves the performance of the system. It reduces the losses and improves the voltage and current profile. Also inclusion of fuel cell in the proposed model has

made the system environmental friendly and also increased the life span of the system.

8. Future Scope of the Research

With the exhaustive literature survey and exploration of the present work, following aspects in electric power quality improvement need to be focused for future research scopes:

- Penetration of grid connected renewable energy system needs to be included in future research.
- Inclusion of smart grid in the system needs to be considered.
- Effect of multilevel inverter in the proposed system needs to be analyzed
- The model can be redesigned taking into consideration the cost factor, which has not been included in the thesis.
- Integration of SCADA systems with the proposed model can be explored in future research.

9. References

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